UAV with Thermal Imaging for High Resolution ET and Water Stress Monitoring in Olives and Vineyards in Chile

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Introduction

✓In the near future, water scarcity will become the main limiting factor for fruit and wine production in Chile.

✓The main agricultural areas of Chile will also face a significant reduction of rainfall (between 20-40%) due to global climate change.

✓Furthermore, Chile is periodically affected by La Niña event, which has produced important droughts and economical losses in most agricultural areas.

Challeges

a) Increase water productivity (kg/m^3)

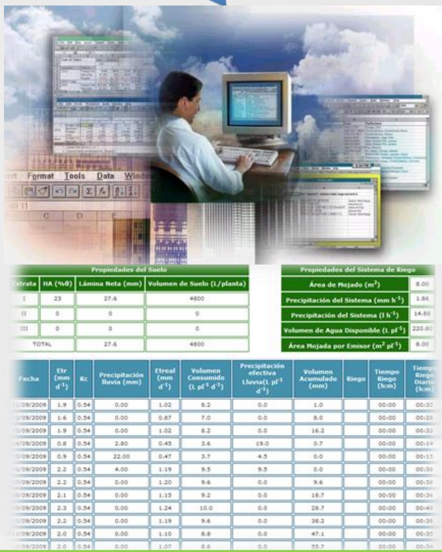
b) Adapt agricultural systems to water scarcity

Geo-Informatics System for Irrigation Management

vineyard → variety → Block

Crop coefficient (Kc)

Reference Evapotranspiration (ETo)



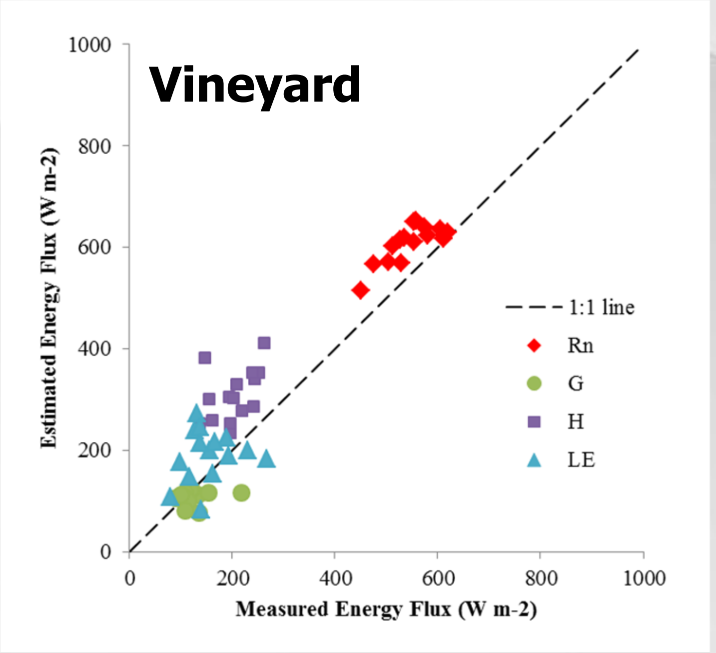
Soil type

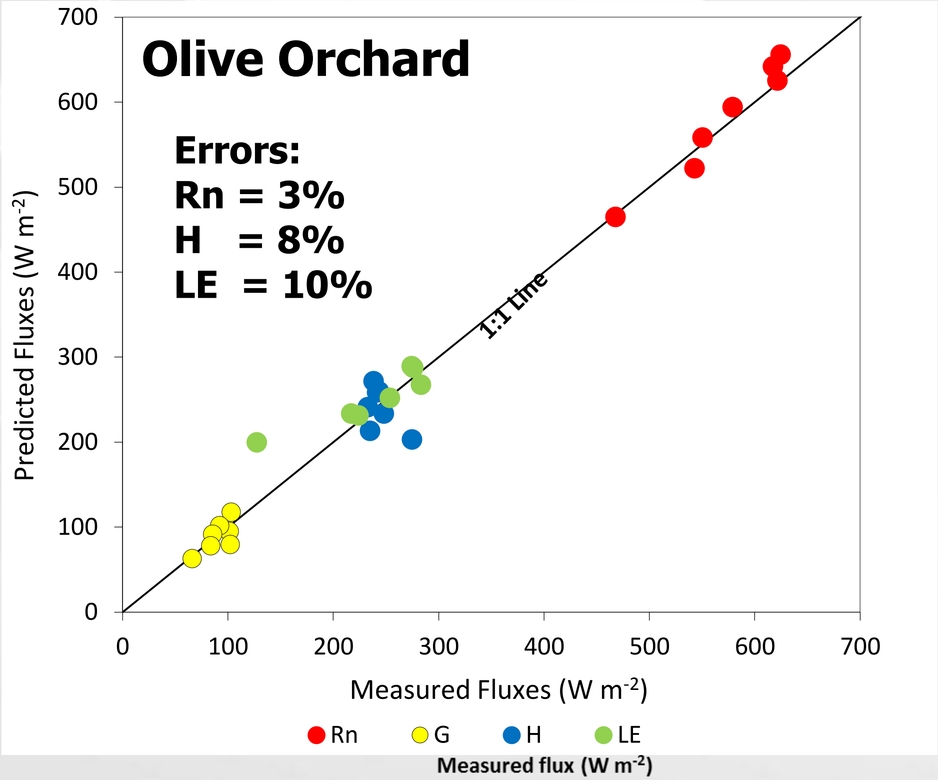
Irrigation system

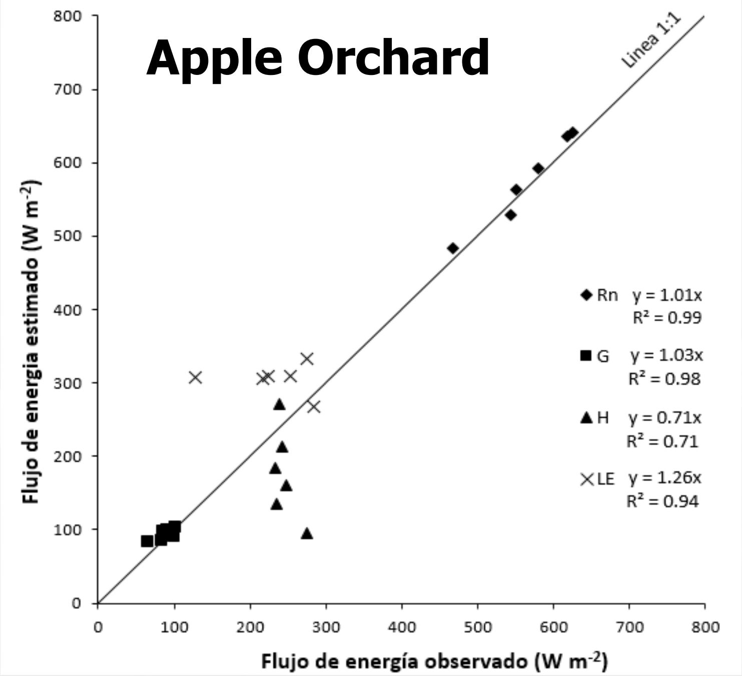
Site-specific irrigation management (Irrigation timing and Irrigation Frequency)

Validation of METRIC model to estimate:

- Latent heat flux (LE) = 8-13%
- Net radiation (Rn) = 8-11%
- Sensible heat flux (H) = 8-18%
- Soil heat flux (G) = 7-11%



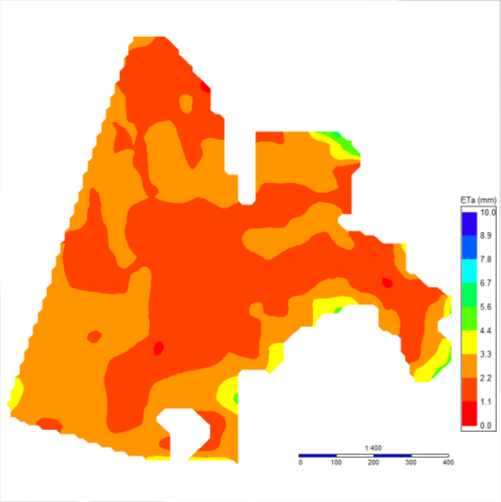




Application of ETa and Kc mapping

Example of ET_a and Kc mapping (period 2007-2008)

ETa Mapping (temporal and spatial resolution)



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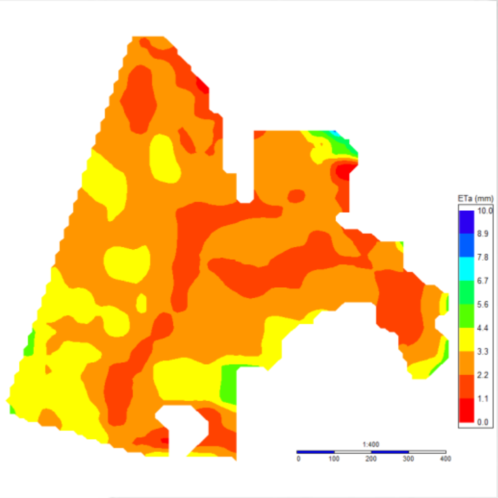

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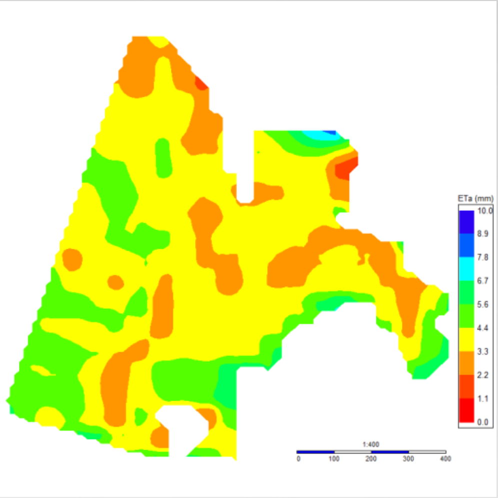

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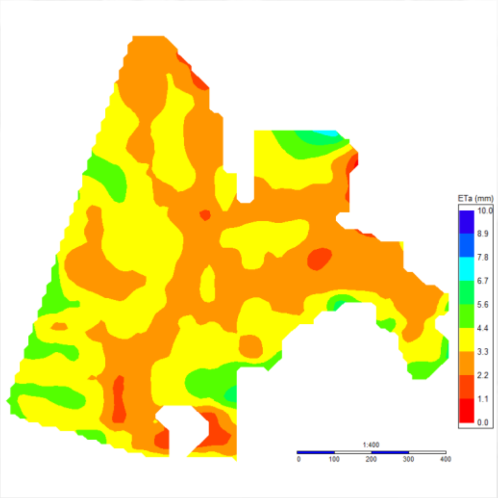

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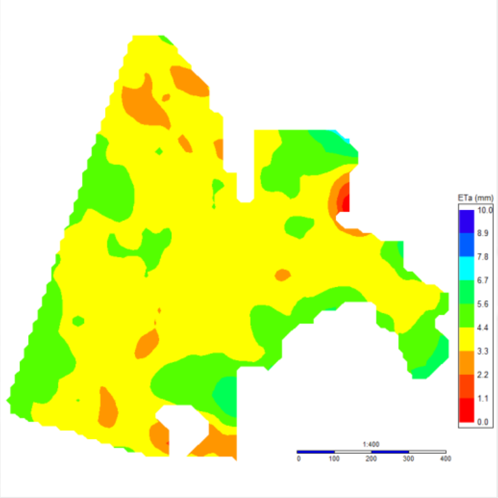

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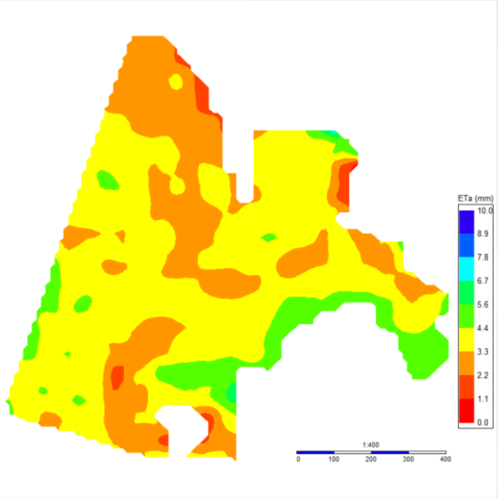
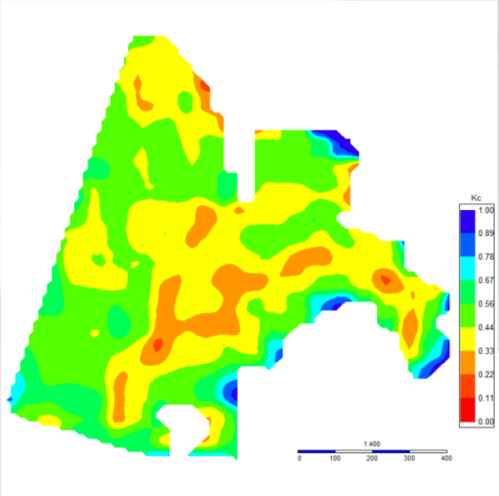


02-02-2008

Kc Mapping (temporal and spatial resolution)



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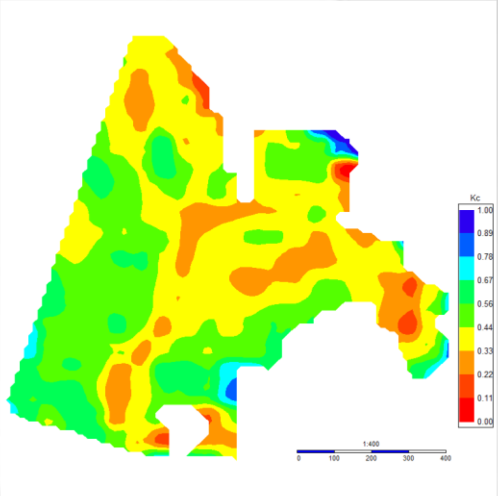

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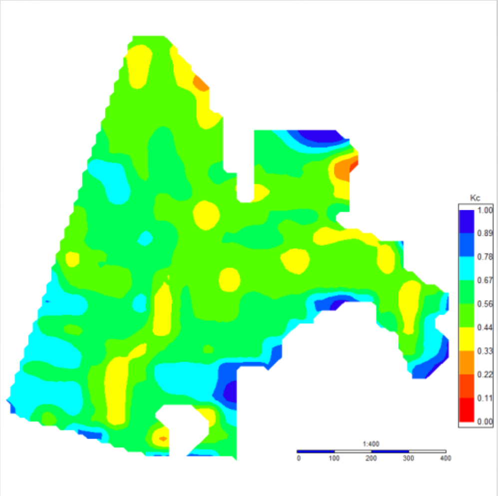

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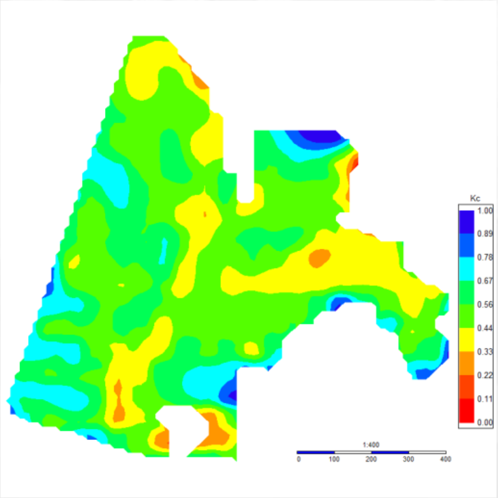

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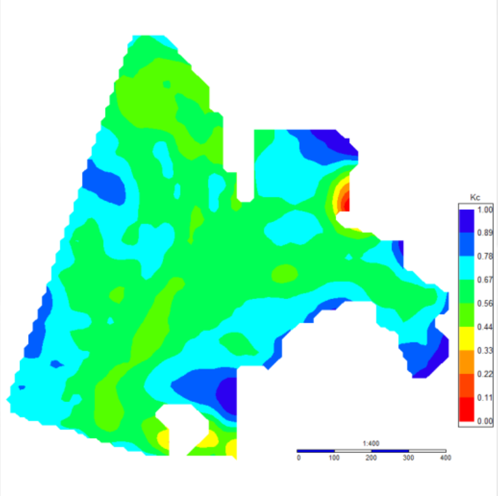

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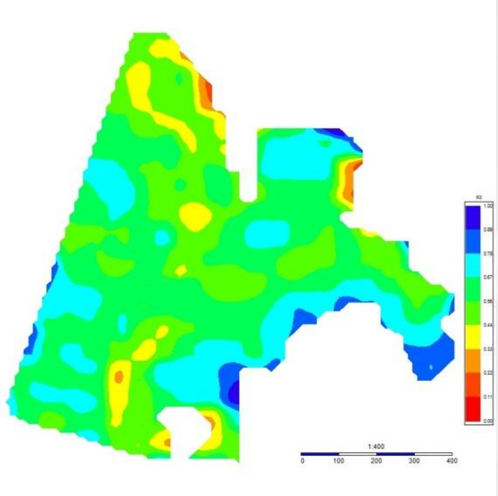

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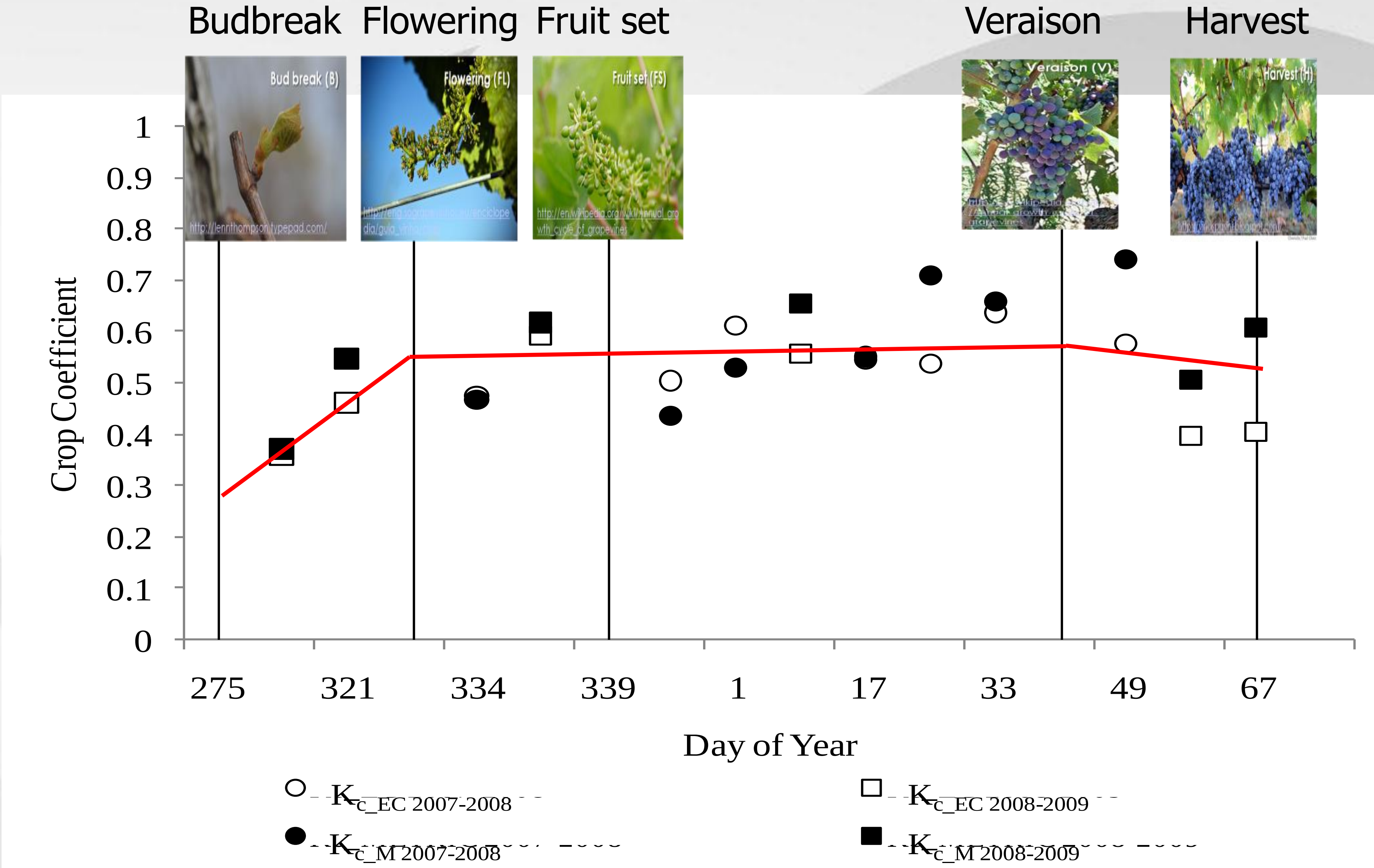


Daily values of crop coefficient obtained by the eddy correlation system (K_{c_EC}) and calculated (K_{c_M}) by METRIC model for the main phenological stages of a vineyard.

ETa Mapping (drip-irrigated olive orchard)

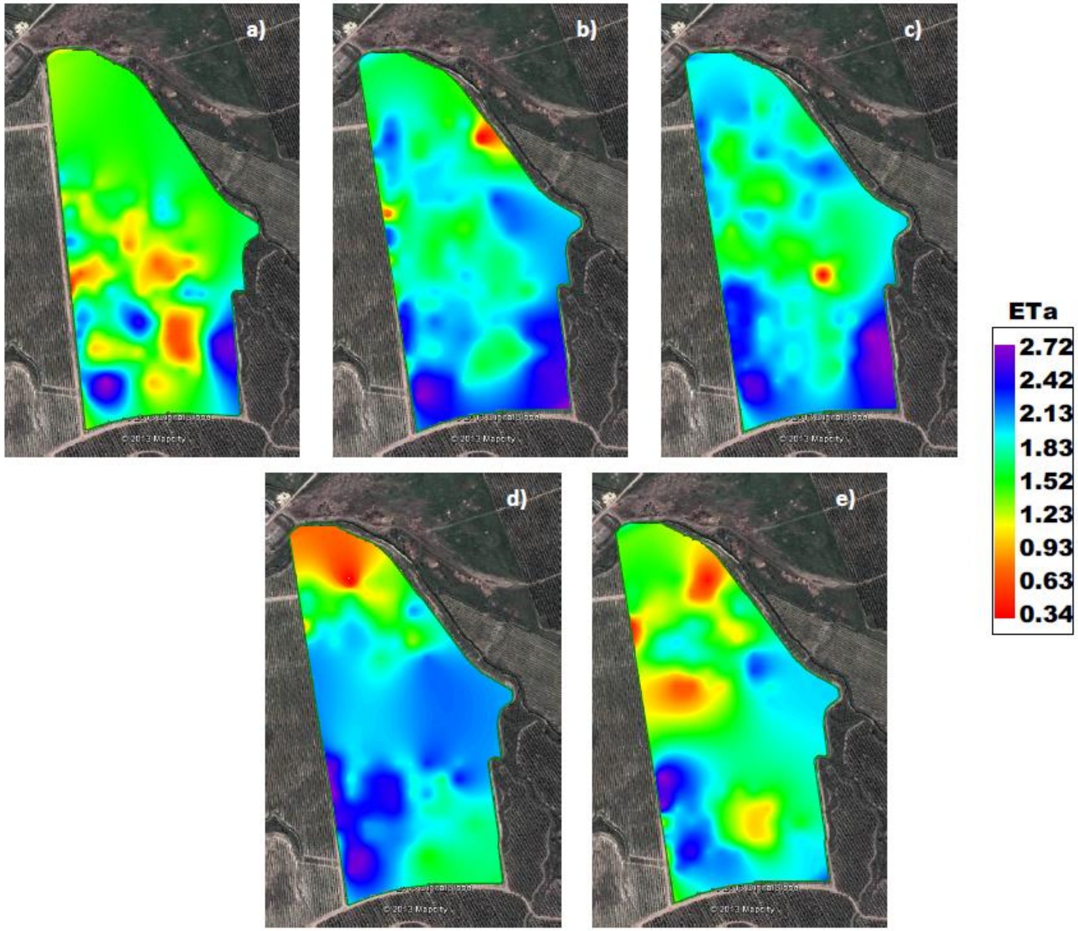


Figura 2. Mapa de evapotranspiración actual para distintos períodos fenológicos en olivos. Olivares de Quepu, valle de Pencahue, región del Maule. a) Fruto alrededor del 30% del tamaño final, b) Fruto alrededor del 60% del tamaño final (endurecimiento del carozo ya finalizado) c) Inicio segundo período de crecimiento vegetativo, d) Segundo período de crecimiento vegetativo en pleno, e) Término segundo período de crecimiento vegetativo.

Limitation of remote sensing energy balance (RSEB) models for site-specific irrigation management are:

a) Satellite overpass frequency = 16 days

b) Cloudy days

c) Spatial resolution: 30m X 30 m. This is related to row spacing (2-5 m) and plant spacing (1-2 m). For orchards and vineyards we need a spatial resolution less than 5m x 5m.

d) Errors in the estimation of H, especially for olive orchards and vineyards where H generated at the soil surface can be the main component of EB equation (H is between 60-75% of Rn)

Spatial variability of vine growth and soil

So, the estimation of ETa and Kc values depend on canopy size, leaf area index, canopy geometry and fractional cover.









Bare soil versus cover crop between rows

Large variability of canopy size, leaf area index and fractional cover.

So, we suggested the use of UAVs with optical sensors at high spatial resolution to estimate ET over heterogeneous canopies.

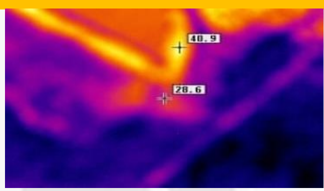
Objectives

- To develop a remote sensing energy balance (RESB) algorithm to estimate olive evapotranspiration using thermal and multispectral cameras placed on board an UAV.

In this case, we select different sub-models from the literature to estimate instantaneous values of Rn, G and H over a drip-irrigated olive oil orchard planted at high density

Unmanned Aerial Vehicles (UAV) (Octocopter)

Thermal camara (Guide EasIR-9)

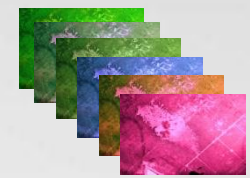


Surface temperature

Digital camera (Lumix DMC)

- Ortho-Mosaic digital imagery

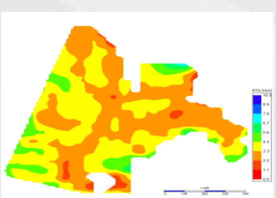
Multiespectral camera (Tetracam Mini MCA 6 channels)



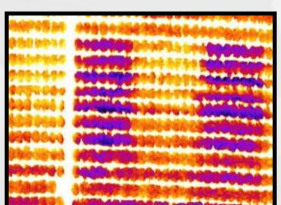
Vegetative Index (IV)

-NDVI
-SAVI
- others

Products

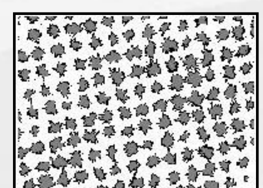


- Evapotranspiration
- Crop coefficient

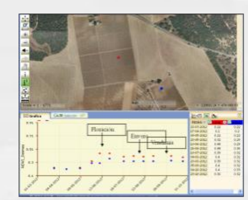


Water stress:
Crop water stress index

Mosaic



Fractional cover
Leaf area index



Evolution of plant growth

Helicopter-based UAV (Octocopter)

1.- Cameras:

a) Thermal (EasIR9) (8000 - 14000 nm)

b) Multispectral cameras (Tetracam Mini MCA (6 channels)

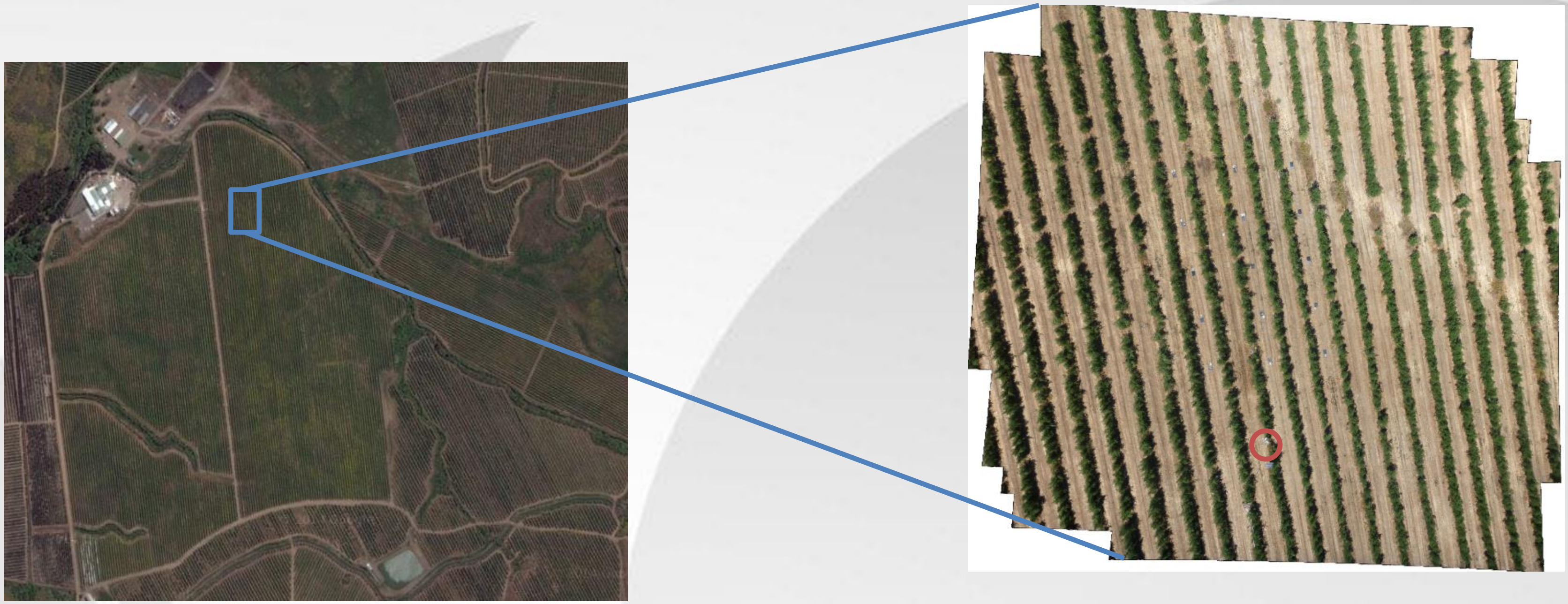
c) Digital camera (Lumix DMC): red, blue and green

2.- Height of flights: 60 m above the soil surface

3.- Duration of flights: 15 min

4.- Time overpass: 12:00 and 13:00 pm

5.- Spatial resolution: 36 cm^2 (6 x 6 cm).



- ✓Cultivar: 5 year-old (cv. Albequina)
- ✓Monocone system (North – south)
- ✓Planting density: 1.3 m x 5.0 m
- ✓Irrigation system : 2 emitters (4 L h-1) per tree
- ✓Tree height = 3.2 m and canopy width = 1.3 m,

Remote sensing energy balance (RESB) algorithm for an Helicopter-based UAV

Multicopter-based UAV

Fractional cover (f_c)

Canopy (T_c) and soil (T_s) Temperatures

NDVI from the canopy and soil

Net Radiation (Rn) from:
- Canopy (Rnc)
- Soil (Rns)

Rn= Rnc*fc+(1-fc)*Rns

Soil heat flux (G) between rows:

G = a+b*Rns

Sensible Heat flux (H) from:
- Canopy (Hc)
- Soil (Hs)

H = Hc*fc+(1-fc)*Hs

Instantaneous latent heat flux over the olive the orchard

LE= Rn-H-G

Automatic Weather Station

Instantaneous latent heat flux over a reference grass LEo

Daily Reference evapotranspiration ETo

Instantaneous Reference evapotranspiration fraction

F = Kc= LE/LEo

Actual evapotranspiration

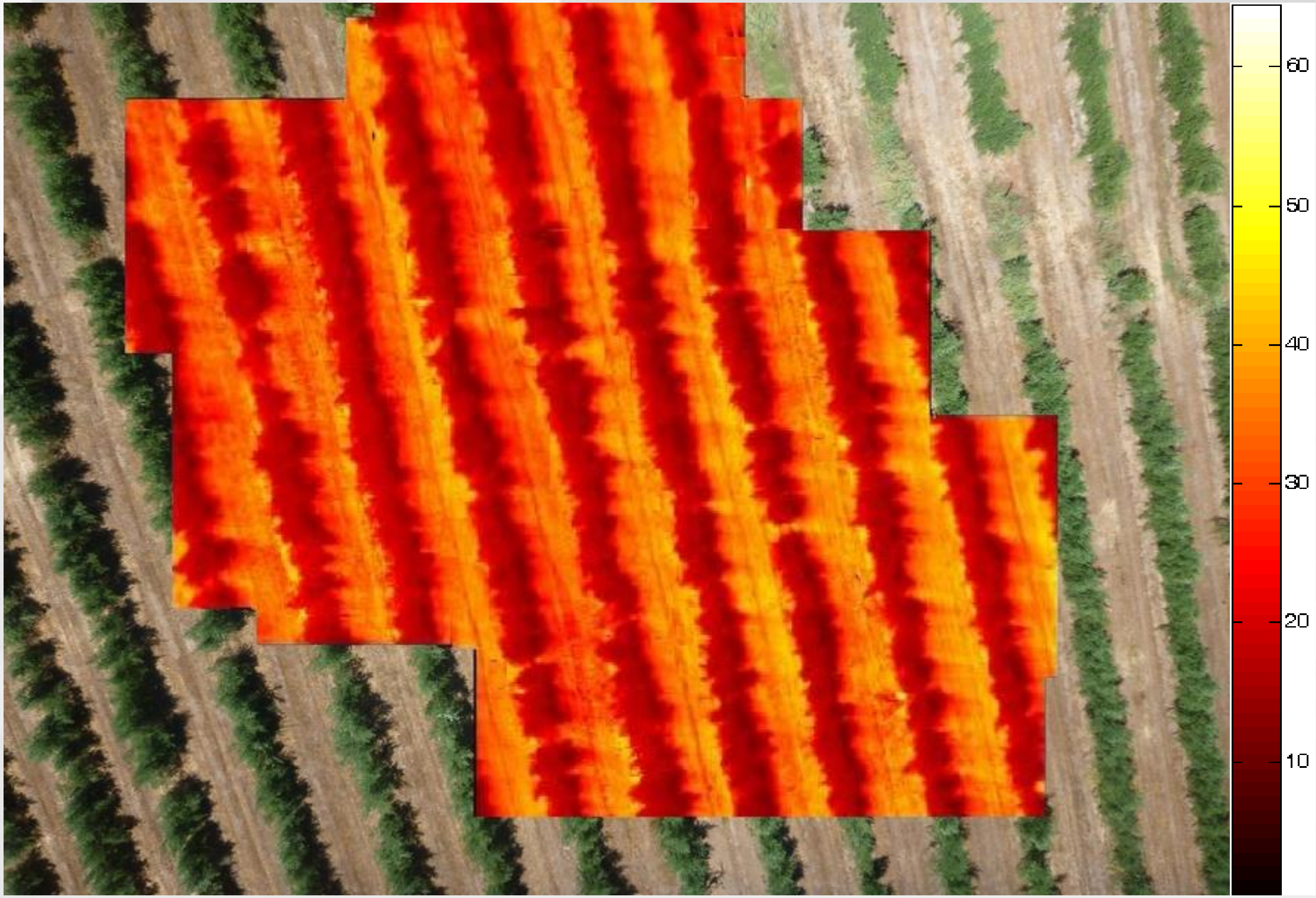
ETa = F*ETo

Results and Discussions

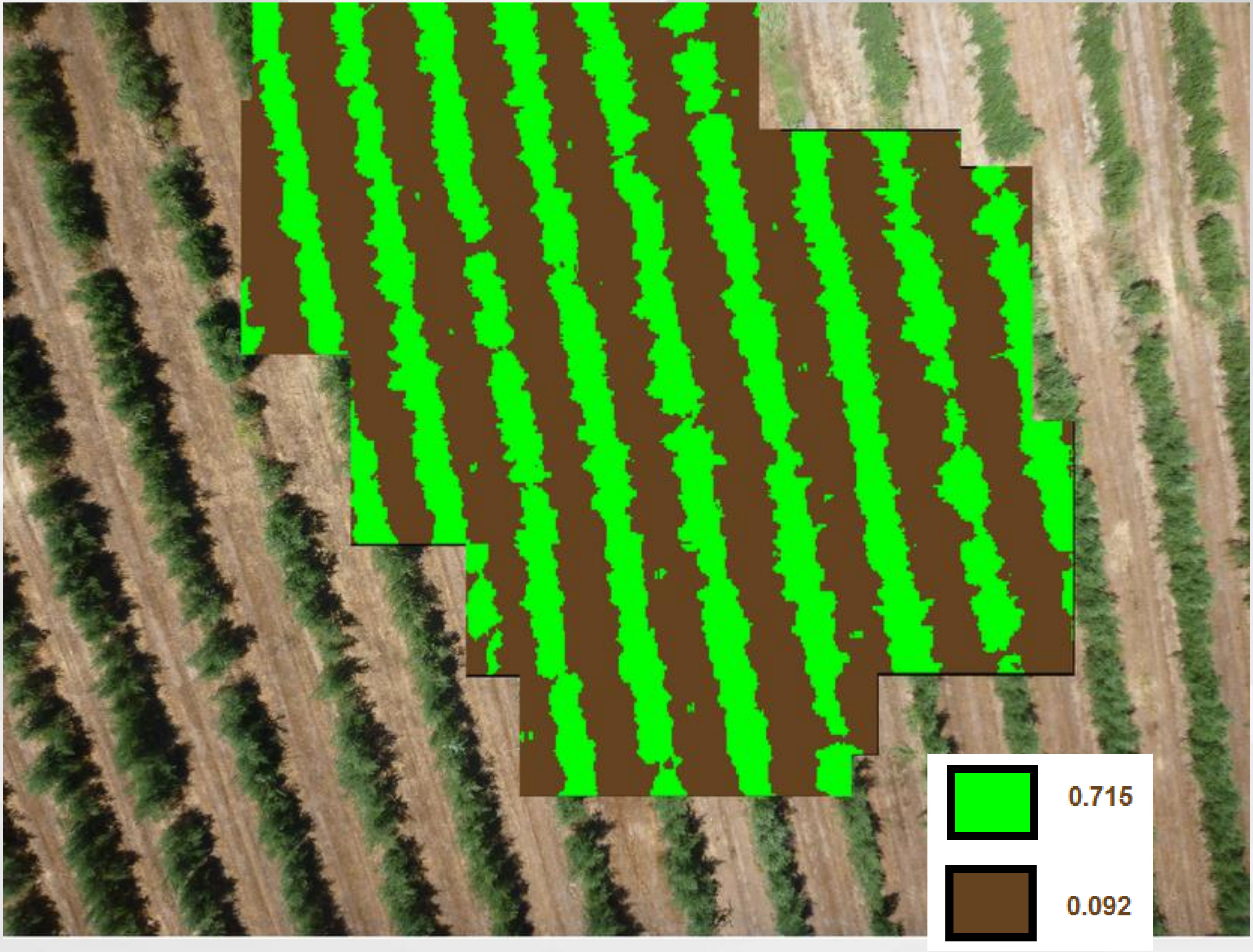
Digital visible camera (28 March 2014), Drip-irrigated Olive orchard

Surface temperature (thermal camara, 28 March 2014) over a drip-irrigated Olive orchard

Canopy temperature = 28°C (± 6°C)
Soil temperature = 46°C (± 5°C)

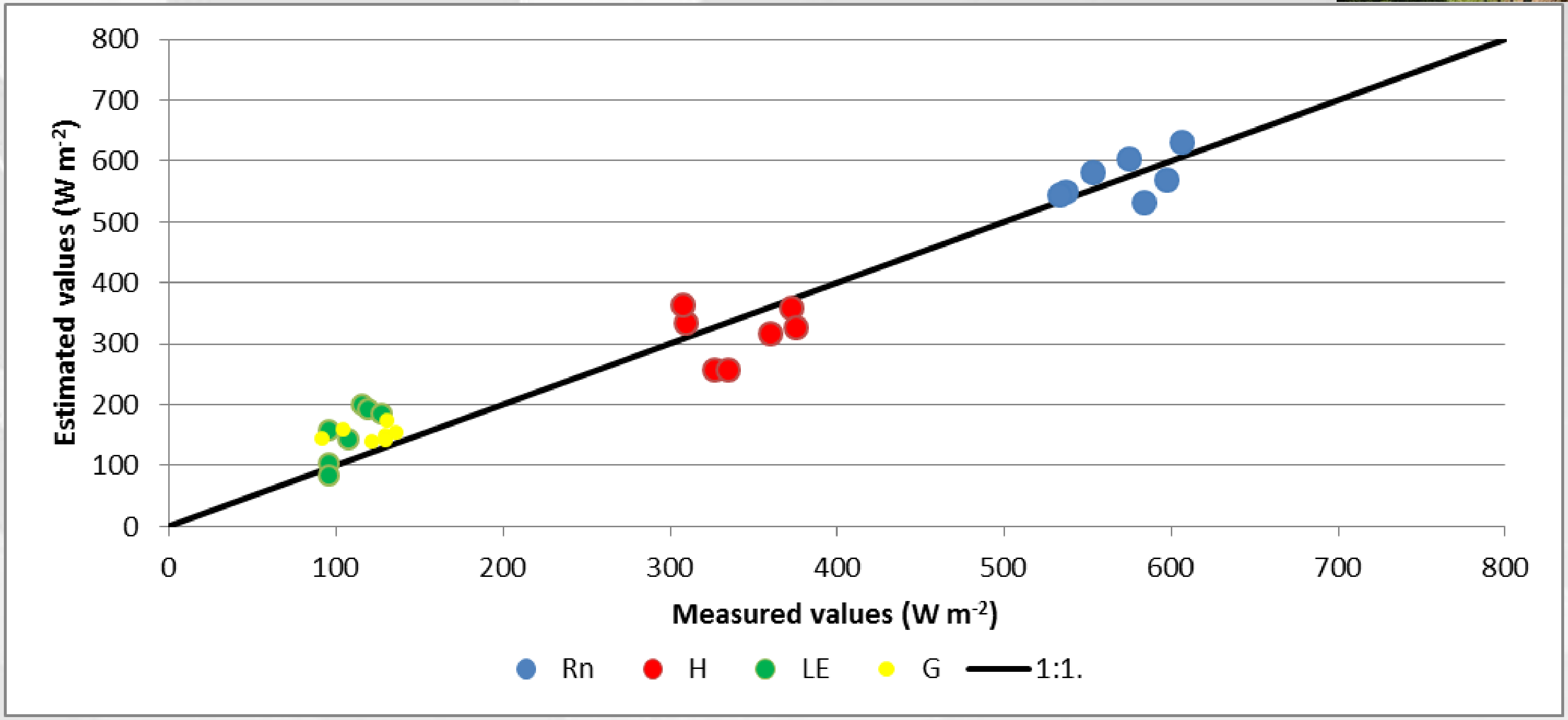


NDVI (multiespectral camera, 28 March 2014) over a drip-irrigated Olive orchard



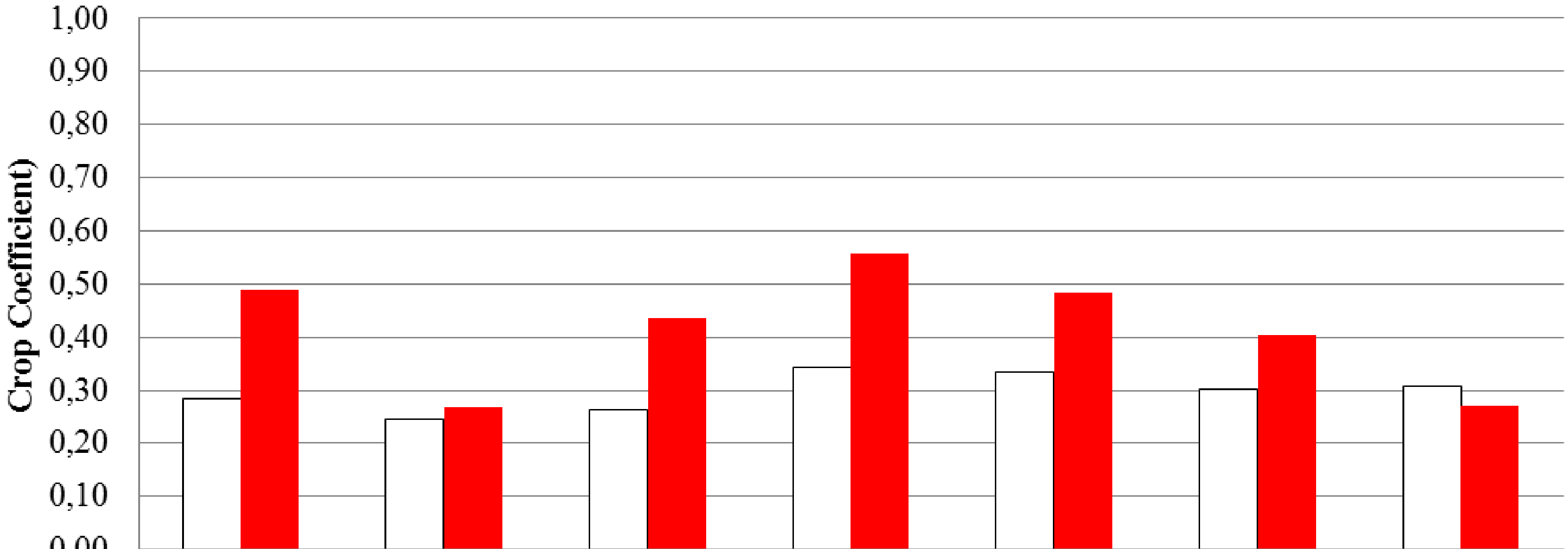
Validation of METRIC model to estimate:

- Latent heat flux (LE) = 14%
- Net radiation (Rn) = 5%
- Sensible heat flux (H) = 12%
- Soil heat flux (G) = 9 %



Comparisons between measured and estimated values of latent heat flux (LE), net radiation (Rn), sensible heat flux (H) and soil heat flux (G) at the time of UAV overpass (12:00-13:00h)

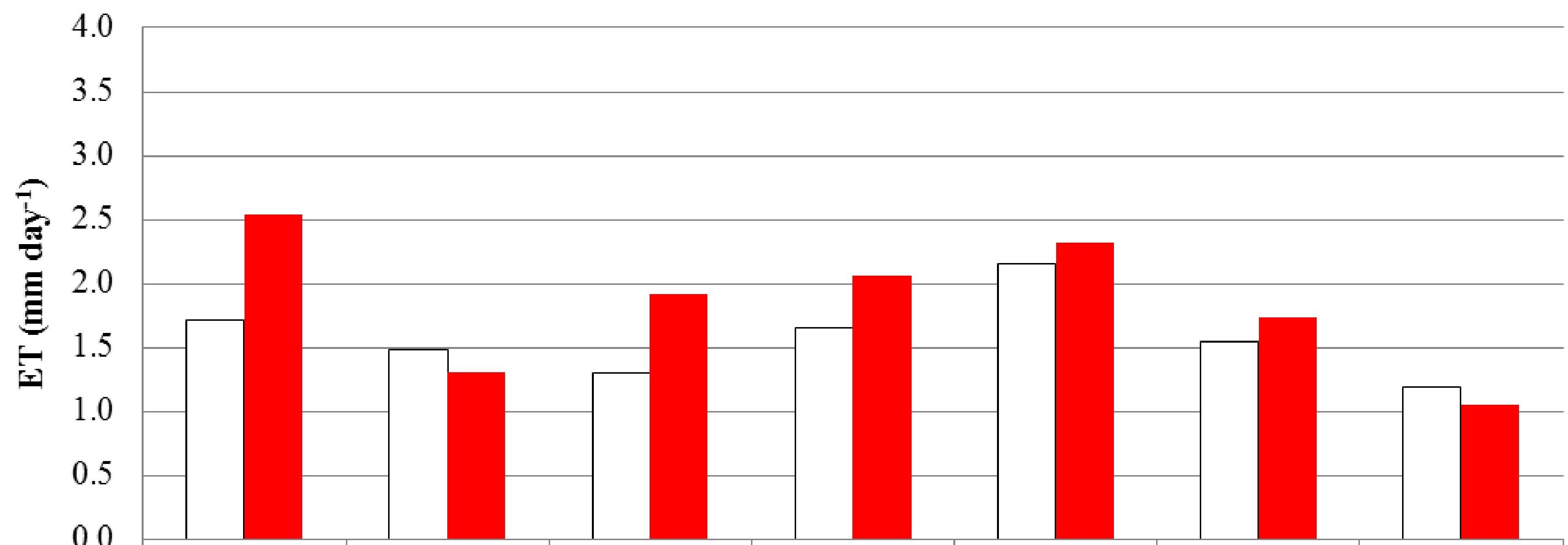
RMSE = 0.12
MAE = 0.08



	27-Feb-00	28-Feb-00	02-Mar-00	04-Mar-00	05-Mar-00	14-Mar-00	20-Mar-00
□EC	0,28	0,24	0,26	0,34	0,33	0,30	0,31
■UAV	0,49	0,27	0,44	0,56	0,48	0,40	0,27

Crop Coefficient obtained using an eddy correlation system (EC) and unmanned aerial vehicles (UAV) for a drip-irrigated olive orchard

RMSE = 0.44 mm day^{-1}
MAE = 0.36 mm day^{-1}

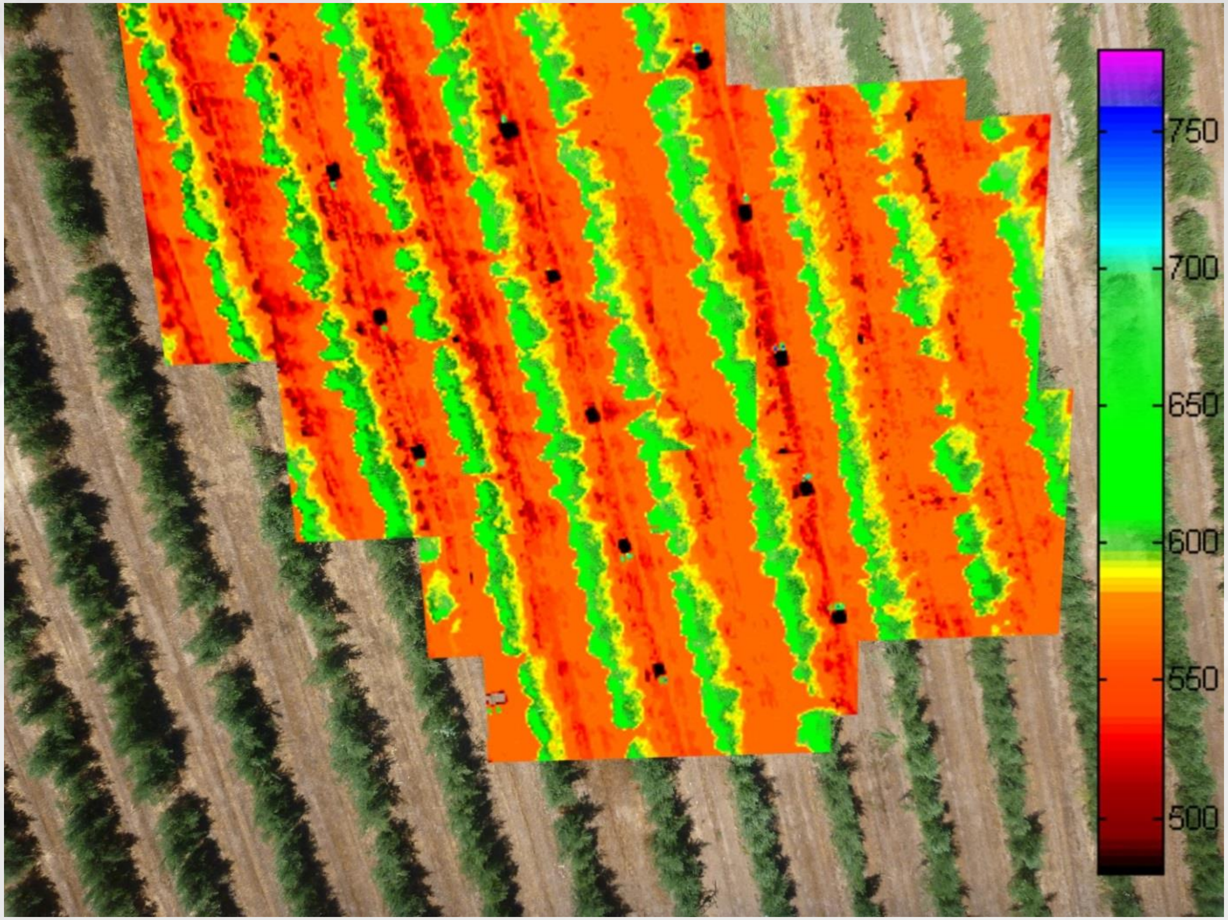


	27/Feb/00	28/Feb/00	02/Mar/00	04/Mar/00	05/Mar/00	14/Mar/00	20/Mar/00
□EC	1.7	1.5	1.3	1.7	2.2	1.5	1.2
■UAV	2.5	1.3	1.9	2.1	2.3	1.7	1.1

Actual evapotranspiration obtained using an eddy correlation system (EC) and unmanned aerial vehicles (UAV) for a drip-irrigated olive orchard

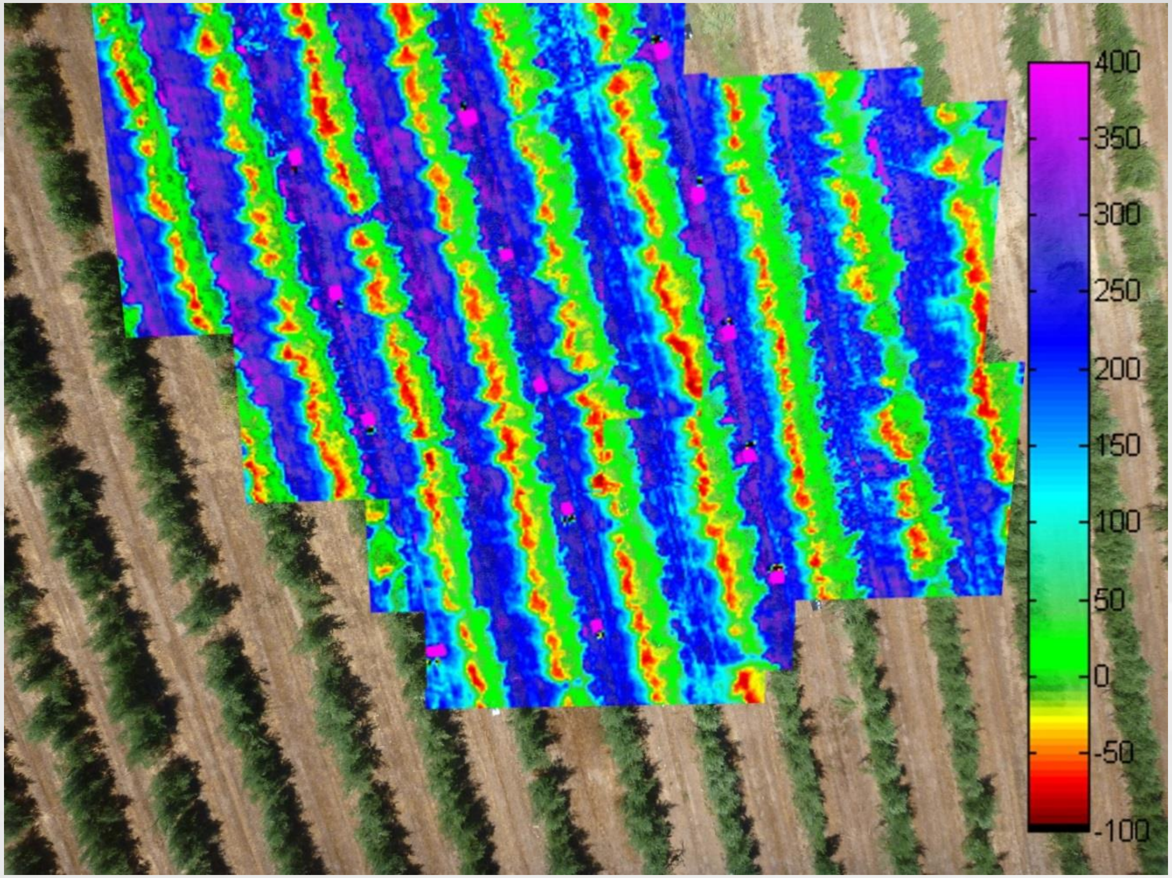
Net radiation (Rn)

Canopy = 600 (± 70) W m^{-2}
Soil = 560 (± 60) W m^{-2}



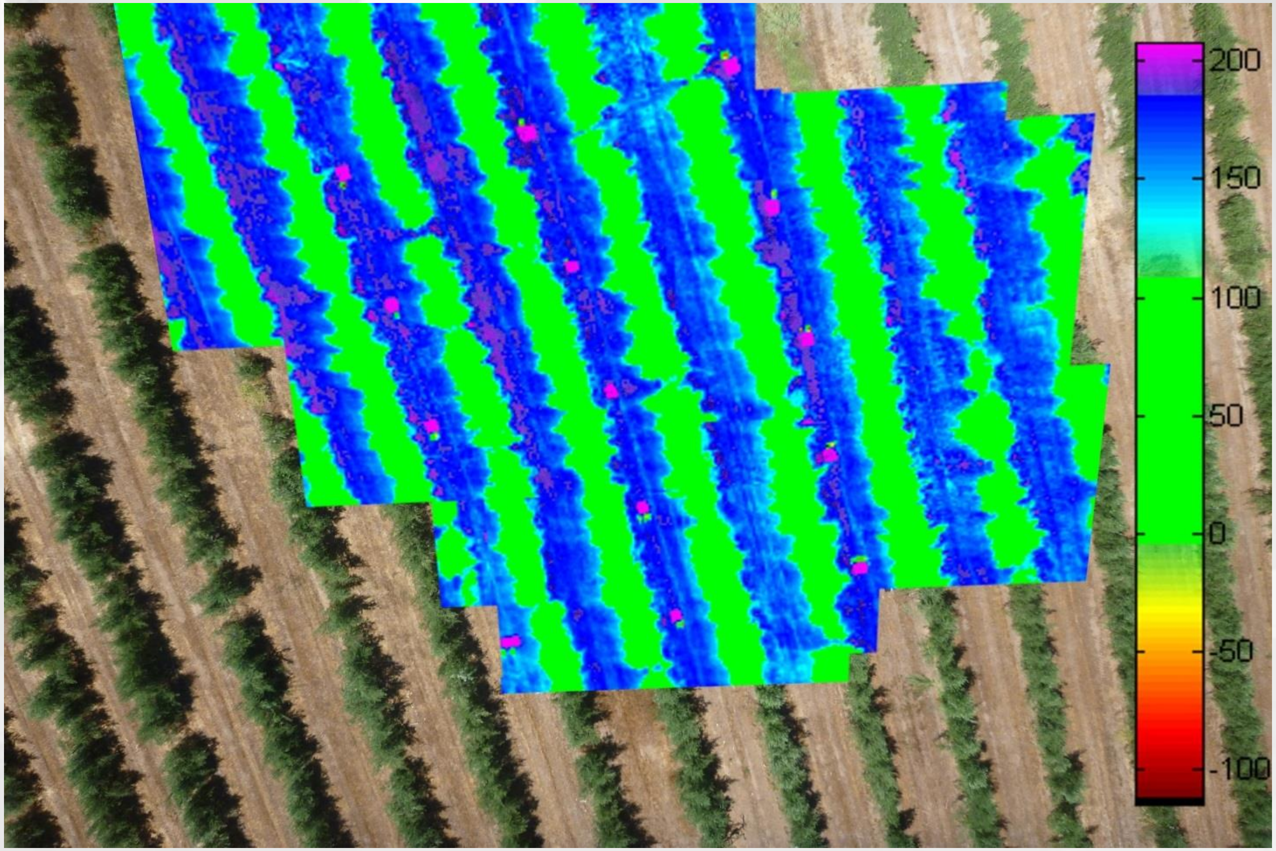
Sensible heat flux (H)

Canopy = 50 (± 70) W m^{-2}
Soil = 310 (± 60) W m^{-2}



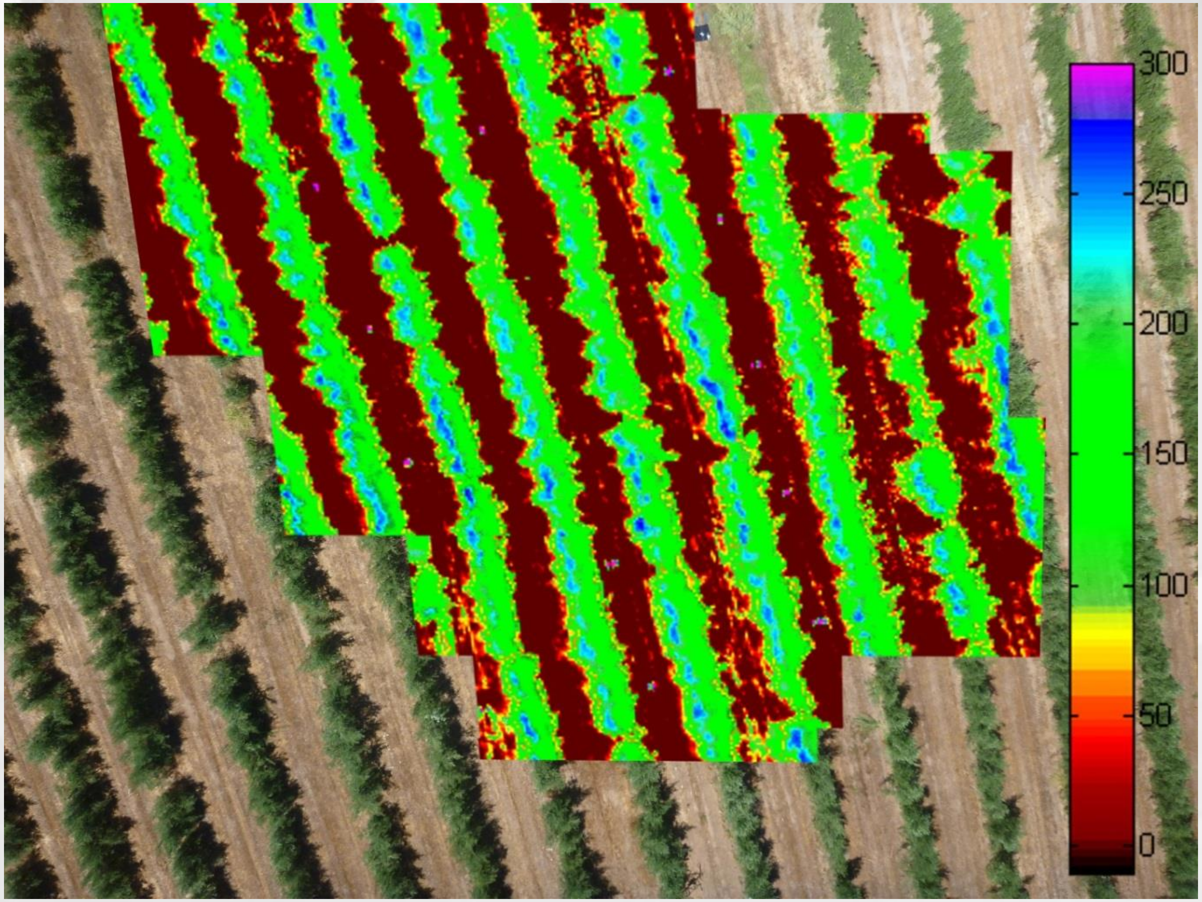
Soil heat flux (G)

Soil = 110 (± 40) W m^{-2}



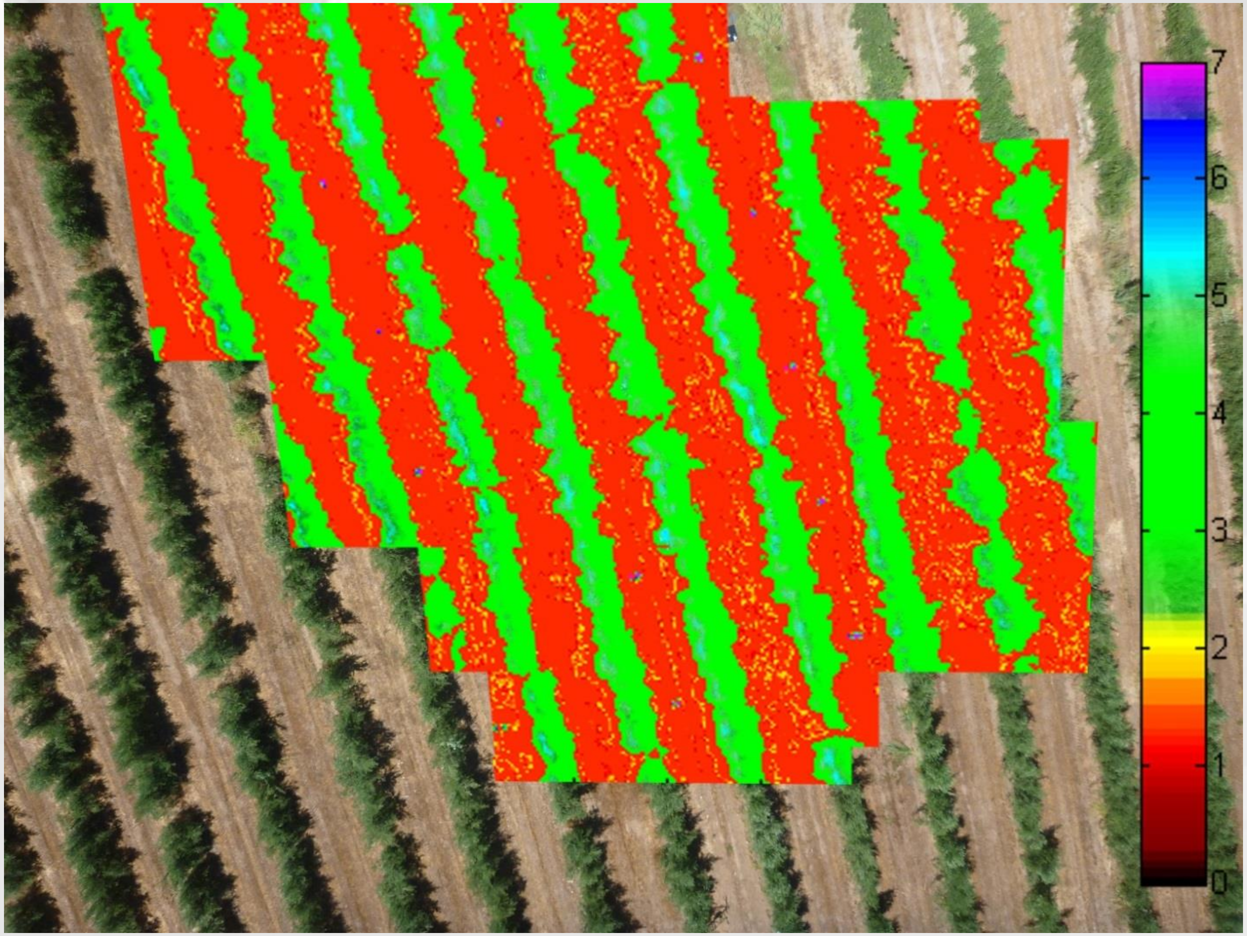
Latent heat flux (LE)

Canopy = 160 (± 70) W m^{-2}
Soil = 80 (± 40) W m^{-2}



Olive evapotranspiration(ETa)

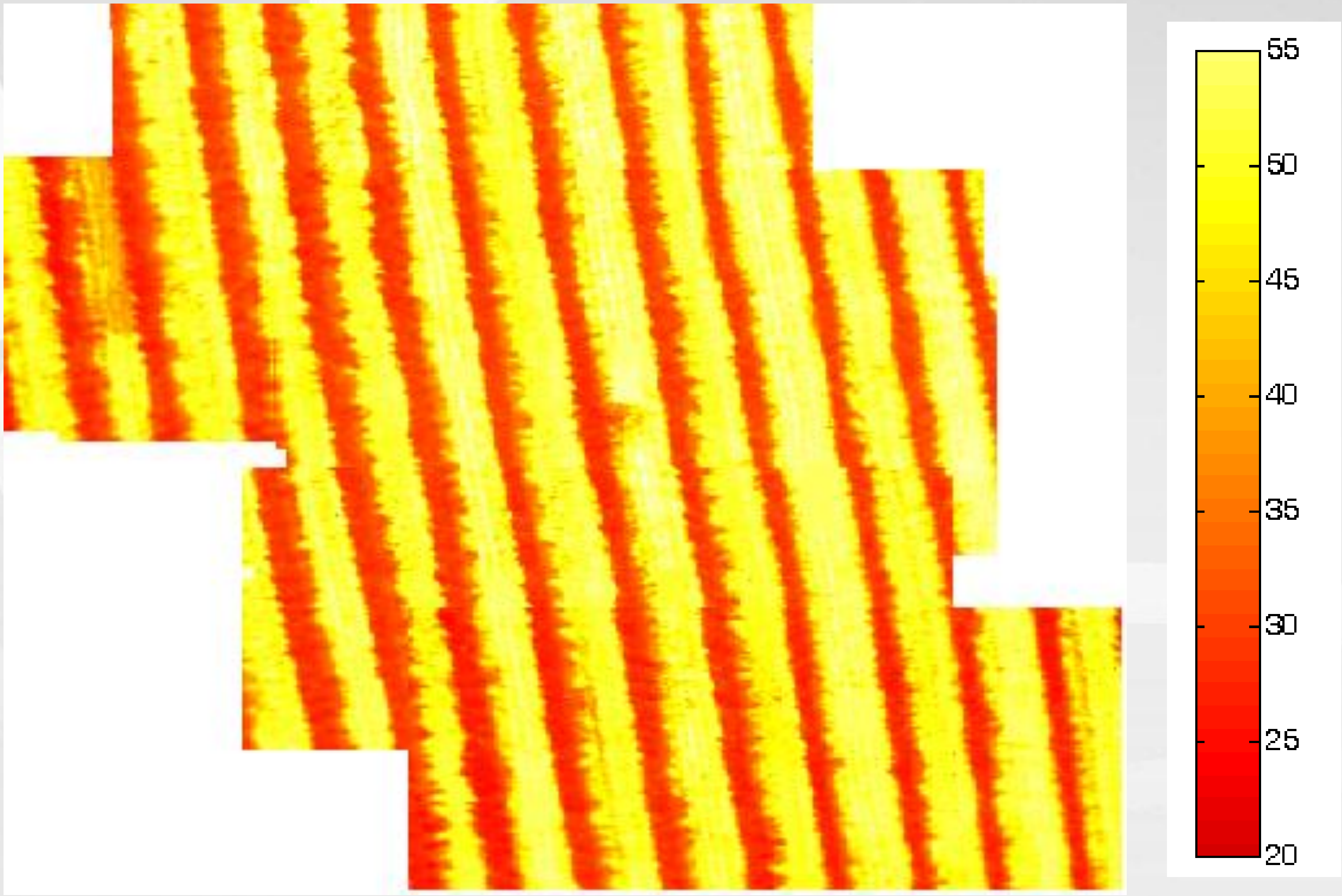
Transpiration = 3.8 mm day^{-1}
Soil evaporation = 0.8 mm day^{-1}
ETa = 1.7 mm day^{-1}
ETeddy = 2.1 mm day^{-1}

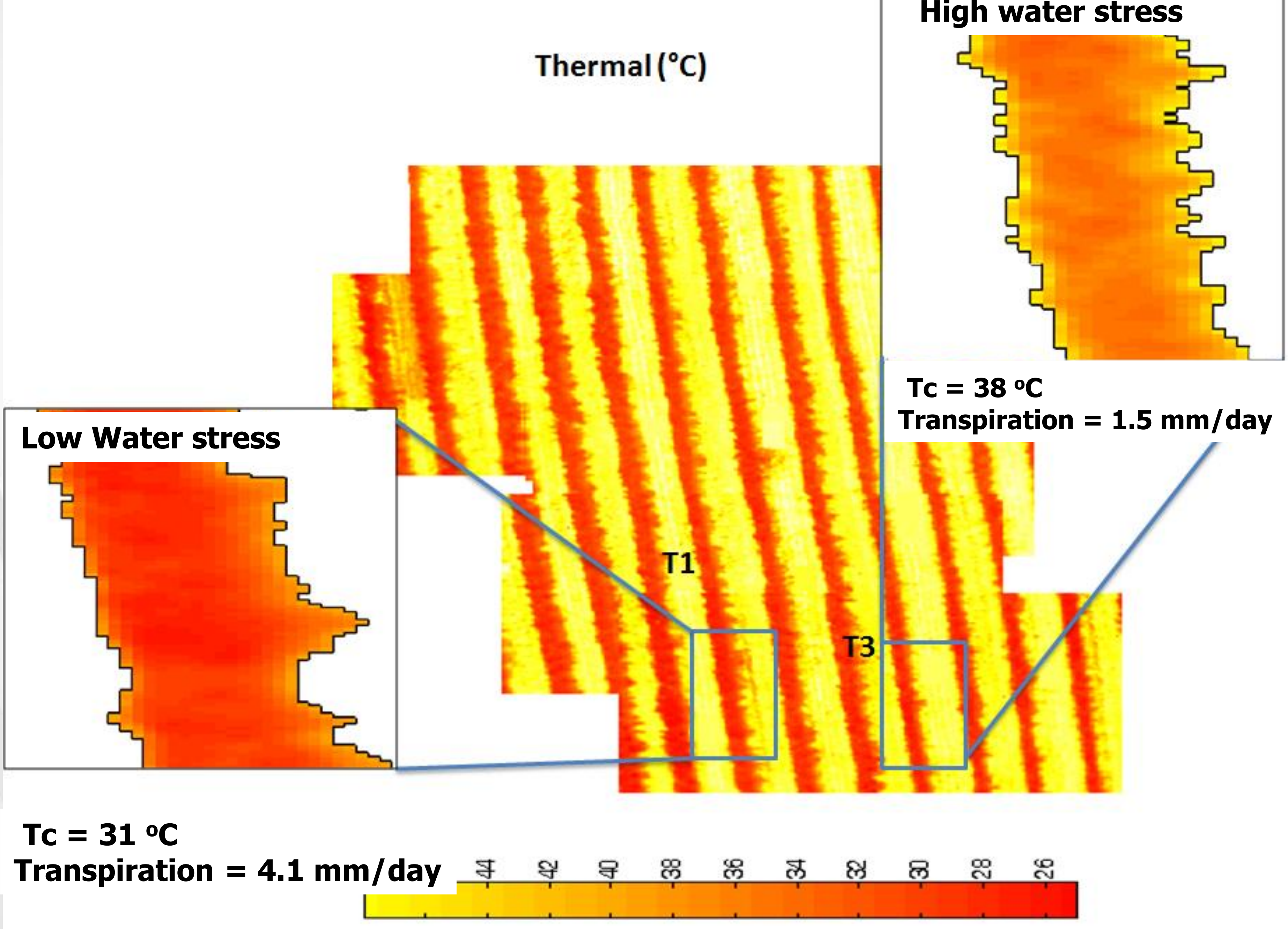


Crop water stress index
(Drip-irrigated vineyard)

Surface temperature (thermal camara, 28 March 2014) over a drip-irrigated Olive orchard

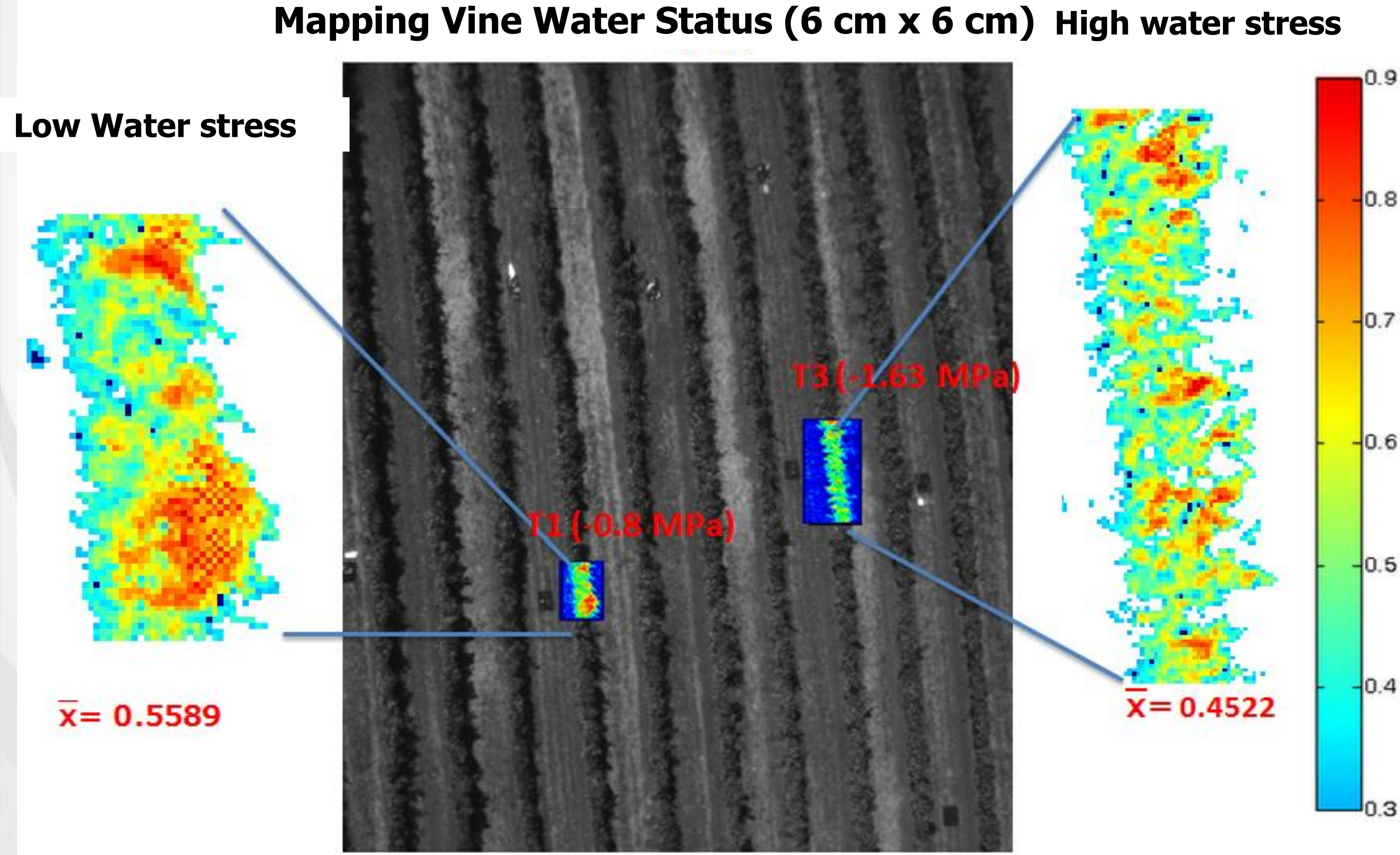
Canopy temperature = 32°C (± 6°C)
Soil temperature = 50°C (± 5°C)





High water stress
Thermal (°C)
Tc = 38 °C
Transpiration = 1.5 mm/day
Low Water stress
T1
T3
Tc = 31 °C
Transpiration = 4.1 mm/day
44
42
40
38
36
34
32
30
28
26

Mapping Vine Water Status (6 cm x 6 cm)



Practical application

- Conclusions

- UAV has the potential to estimate evapotranspiration and plant water status at high spatial resolution.

- UAV can be a potential tool for applying the site-specific irrigation management

- Data from UAV can be used to validate and calibrate the remote sensing energy balance (RSEB) models.

Mapping grapevine water stress at high spatial resolution.